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SILVER BIRCH (*BETULA PENDULA* ROTH.) AGE-CLASS COMPOSITION AND NATURAL REGENERATION FEATURES IN RUDNY ALTAI CONDITIONS

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1. Abstract
Silver birch (*Betula pendula* Roth.), along with Siberian fir (Abiessibirica L.) and aspen (Populustremula L.), is one of the most common tree species in mountain forests of Rudny Altai. Due to its ecological and biological characteristics, is the first species that appears in areas cleared by forest fire or clear felling, thus causing species replacement. It regenerates not only by seed, but also vegetative, through the formation of accessory and dormant buds located on the stump and root spur. The silver birch rarely regeneratesby root stalks. Shoot formationability depends on the origin and age of the cut tree. This article presentsthe results of a study about the age-class composition and vegetative regeneration features of the silver birch. Studied birch stands are as per definitionof different ages. Shoot formationability is determined depending on both origin and age. The study showed that stumps with a diameter of less than 40 cm and tree age of up to 60 years have the best ability for natural regeneration by shoot formation. Subsequently, shoot formationability is reduced and completely ceases when reachingage class VIII. The shoots originated from accessory buds located on theroot spurplay a key role in birch shoot formation.

2. Keywords: Silver birch; Age-class composition; Vegetative regeneration; Shoot growth

3. Introduction
3.1. Birch species
The birch is the most important forest-forming species in different forest zones of the Republic of Kazakhstan, including Rudny Altai. In accordance with the system of forest growth zoning (Seversky, 1971), a western skirt of the Altai-Sayan mountain forest vegetation area is isolated tothe Western Altai forest growth province, and its south-western part to a special region - Southwest district of fir forests (Rudny Altai). A considerable reserve of warmth and adequate moisture contributes to the formation of particular type of dark coniferous forests - black taiga, where the main forest-forming species is the Siberian fir. Commercial development of the fir forests and fires led in the past to significant changes in forest fund composition and structure. Currently, large forest areas are occupied by aspen and birch regeneration. The birch quickly takes open areas due to the ability to produce large quantities of seed and the rapid growth of shoots (Fischer *et al.*, 2002).

If we consider the species of local birch, we can say with confidence thatthe silver birch (*Betula pendula* Roth.) is the most widespread in Rudny Altai (Mushegyan, 1962, 1966) (Figure 1). In Kazakhstan there are also some other common birch species. Their diversity is determined by area geography and site altitude. For example, in the Northern and Central Kazakhstanthe white birch (*Betulapubescens*Ehrh.) is the most common one.

Figure 1: Silver birch (*Betula pendula* Roth.) in Rudny Altai conditions. In Figure 1 (to the left) - isolated trees, (to the right) - birch stand.

The distinctive features of the white and silver birch are not only the differences of leaf and branch morphology, bark color, seed weight, but also the cell size and the anatomical structure of wood (Kujala, 1946; Johnsson, 1974; Bhat and Karkkainen, 1980; Jonsell, 2000). In Rudny Altai, at 1800-2000 m above sea level you can also find dwarf birch (*Betulafruticosa*Pall.).

The visual identification between the birch species can be difficult, but there are identification methods based on the chemical properties of the bark (Lundgren *et al.,* 1995), as well as on the number of chromosomes (Helms and Jørgensen, 1925). Silver and white birch hybrids are considered rare (Jonsell, 2000) due to the incompatibility of biochemical mechanism between these species (Hagman, 1971). Both species have a large natural habitat on Eurasian continent from the Atlantic to Eastern Siberia (Hultén and Fries, 1986).

3.2. Birch resources

The birch has a sufficiently wide growth area. According to Hynynen (2010), in Northern and Eastern Europe silver birch is an important commercial species. Its share of the total wood stock in the Scandinavian countries varies from 11 to 16% and in the Baltic countries - from 17 to 28%. In Central and Southern Europe, where the share of birch is only a few percent, it plays a secondary role in the forest sector. In Russia and Belarus, the birch is considered a commercial species, but still is of secondary importance.

In Rudny Altai'sforestry silver birch, until recently, did not draw attention because of its small stocks, as it was a single additionamong the dark coniferous forests. However, forest fires and intensive use of fir forests in the second half of the last century contributed to the formation of large areas of secondary birch forests. According to the latest forest management (Basic Provisions, 2009), the total area of birch forests has reached more than 200 hectares with a total stock of more than 16.5 million m^3 (Table 1). Thus, the portion of birch trees in forested lands of Rudny Altai is 21.4%. Dynamics of birch areas accumulation in the region will be further positive due to ongoing clear felling of fir forests.

Age-group distribution of the birch stands given in Table 1 indicates that a predominantarethe stands of III-VIage class, which form 119225.6 ha (58.5%). Among them, the stands of the III age classis 15.2%, IV age class – 20.8%, V and VI age classes are 10.3% and 12.5% of the total area respectively.

3.3. Growth conditions and types of birch forests of Rudny Altai

The birch is considered sufficiently fastidious to the soil (Koivisto, 1959; Fries, 1964; Raulo, 1977; Oikarinen, 1983; Gustavsen and Mielikäinen, 1984; Niemistö, 1995). The most important habitat characteristics are adequate moisture and soil saturation (Hynynen *et al.* 2010).

Indicators	Age groups					Total
	Young growth, I and II class	Middle-aged, III-VI class	Approaching maturity, VIIclass	Mature, VIII and IX class	Over-mature, X class and above	
Area, ha stock, thou. m3	10035.3 247.58	119225.6 8602.4	31758.4 3134.74	39152.1 4454.48	2145.3 244.73	203048.0 16683.91
% of total area	4.95	58.8	15.8	19.4	1.05	100
% of total stock	1.4	51.6	18.8	21.8	1.4	100

Table 1: Age-group distribution of the birch stands (numerator - area, ha; denominator - stock, thou. m^3).

The best forest areas for the silver birch, in his opinion, are mechanical composition soils from sandy to fine sandy loam. This species grows poorly on infertile soils. Clayey and muddy soils are not suitable for birch, as it suffers from excess moisture.

Birch forests of Rudny Altai cover mild and downhill slopes at 400-800 m above sea level and grow in the mountain-forest gray, dark gray, slightly or latent-podzolized soils (Biryukov, 1982).

Their composition ranges from 10B to 5B5F and depends on the ontogeny stageof temporary birch forest, and corresponds to the I-II and III quality class by growth conditions productivity. Liveground cover is dense and represented by tall grasses. The ferns are arelic.

There are four types of birch forestsfound in the conditions of Rudny Altai (Table 2). Marsh and forest-steppe birchforests are theprimary ones and occur as small areas along the river-valleys, streams, shallows on light gray clay-loam and peat-bog soils. Their area forms 5.41% of the total birch forest area.

Types of birch forest	Index	Area, ha
Swamp birch forests	SBF	334.8
Birch forest-steppe	BFS	10637.6
Ferny-mossy birch forests	FMB	11037.4
Grassy birch forests	GBF	181038.9
TOTAL		203048.7

Table 2: Rudny Altai's birch forest distribution by types.

Poor birch stands (IV or V, Va classes) take their natural niche in conditions that do not allow the growth of conifers. A different matter issecondary birch forestscoveringareas fired or exposed to clear felling in fir forests, among which pine grass forest stands out and occupies 181.0 hectares, or 89.16% of the total birch forest area.

4. Methods

The object of the studyare the secondary birch stands of Rudny Altai of natural origin, as well as birch forest areas formerly cleared by clear felling. Temporary sample plots (hereinafter - TSP) were pledged according to OST 56-44-80 (1980), OST 56-69-83 (1983) at a distance of at least 30m from the roads, glades, meadows, and separatedby thealigner; the poles were fixed at the corners. TSP were pledgedwith a view tothe number of trees is at least 150-200 pieces of a primary element of the stand. Temporary sample plots are rectangular or square with an area of 0.18-0.4 ha. Complete enumeration of the trees was carried out on all TSP. The diameter was measured at a height of 1.3 m and 0.25 m (near the stump) using 2 cm caliper scale. The age of each tree (except sphacelate) was determined using increment borer at a height of 0.25-0.3 m above the ground. After determining the average diameter in nine birches (three from each of most occupieddiameter class) the heightsweredefined. Sphacelate, windfal ltrees and snags were considered individually.

Stumps diameter was measuredon birch 2-10-year old felling areas using 2 cm caliper scale. Each stump was determined by the presence of coppice shoots, their location, origin, number and height. Major representatives of young growth, undergrowth and live ground cover, as well as their placement and density were identified visually.

5. Results and Discussion

5.1. Characteristic of secondary birch forests of Rudny Altai

As a result of the full-scale study of secondary birch forests, it is noted that they can be nominally divided into three groups:

1) First generation birch forests arose after fires (pyrogenic) or clear felling and represented the first stage of forest forming process. They consistof birch by 100% with some single aspen and fir trees. The origin of birch is seed. This is the most productive stand (Figure 2).

Figure 2 First generation pyrogenic birch forests with 10B composition

Figure 3 Second generation birch forests with 6B4F composition

Figure 4 Near settlement birch forests (3-4 generation)

2) Next generation birch forests with 9B1F-5F5B composition represent different stages of forest forming process, where the birch forests are naturally transformed to fir forests influenced by the time. Such stands may include trees with seed or vegetative origin (Figure 3).

3) The most accessible birch forests are located near population centers, where the birch stands are intensively used for firewood stockpiling throughout the growth. They are characterized by the predominance of vegetative birch origin (Figure 4). Productivity is significantly inferior to the first two birch forests groups.

5.2. Age-class composition of secondary birch forests

Age-class composition of the first generation was studied on the territory of Cheremshansky forest enterprise. Pyrogenic birch forests are widespread not only in that forestry, but also in the whole forest fund areaof the region, so theobtained findings can be representative for the whole territory because of the similarity of birch foreststypes.

The studies were conducted in pine grass (PG) birch forests on the slopes of NW-N-NE exposures of 3-7º steepness. Stand composition is 10B; density is 0.8-1.0. The average density of trees is 774 ± 115 pcs/ha (from 525 to 1138 pcs/ha). The average stock per 1 ha is 471.5 ± 33.69 cum (from 386.36 to 611.9 cum/ha). The trees are distributed evenly on temporary sample plots. Fir regeneration up to 5.0 m is found within a radius of 30 m from the fir seed-breeding plot. There is no birch regeneration. Bird cherry, mountain ash, honeysuckle, willow, and others represent the shrub layer. Cereals predominate in live ground cover. Nineteen sample plots were pledgedin the most typical areas. Age-class distribution of the birch trees is given in Table 3.

Indicators	Ageclass							Total
	II	III	IV	V	VI	VII	VII and above	
Average number of trees per 1 ha, %	0.8 ±0.13	1.5 ±0.42	2.0 ±0.03	12.1 ±2.32	9.6 ±1.75	73.7 ±4.0	1.9 ±0.7	100.0
Age-class stock, %	0.0	0.1	0.3	4.9	3.4	88.8	2.5	100.0

Table 3: Age-class distribution of the birch trees on sample plots.

There are II-VIII age class trees found in the stands. The VII class is the dominant where 73.7% of all trees (from 63.3 to 89.5%) are concentrated. The trees of other age classes constitute 26.3%, in which V and VI classespredominate constituting 21.7%. Other age classes (2,3,4,8) account for 4.8%. Thus, the V age class trees and above predominate in the secondarybirch stands of the first generation. The stock of VII age class trees is 414.5 m³/ha (88.8%), the remaining 11.2% of stockaccrues to the other classes. Thus, V age class trees and above constitute 99.6% of stock.

According to the current forest stand classification by age structure (Lugansky et al., 1996), the birch stands studied are conventionally uneven-aged because they contain II-VIII age class trees. However, the stock of II-VI and VIII age class trees is 11.3%, which does not allow calling them uneven-aged.

The diameter of the trees (at a height of 1.3 m) forming original forest stand ranges from 6 to 68 cm. The diameter of the trees composing II-IV age classes ranges from 6 to 16 cm. The trees with a diameter of 14-18 cm refer to V age class, 20 cm - VI; 22-42 cm - VII and from 44 cm and more to VIII and above.

One of the objectives of the study of birch forests age structure was to determine the relationship between the diameters at a height of 0.25 m (at the stump level) and 1.3 m. The resulting regression equation $Y = 0.854x-0.991$ ($R2 = 0.999$) and its application allows to identify indicators of the original birch standby felled trees of all ages.

5.3. Natural regeneration of birch

Due to biological characteristics and originality of long-term and seasonal development cycle, the birch and aspen predominateduring natural forest regeneration after disasters or felling, thus causing species replacement. Species replacementtheorywas developed in the writings of the first forest researchers G. F. Morozov (1913, 1930), V. N.Sukachev (1928), I. S.Melekhov (1948), M. Ye.Tkachenko (1955) and continued by the foresters observedsuccessionprocessesin the various forest areas of the former USSR and abroad (Kolesnikov, 1960; Chernyshev, 1963; Kurbatsky, 1964; Komin, 1967; Sannikov, 1973; Popov, 1983; Romanovsky, 1996; Kalachev, 1998, 2001; Götmark *et al.* 2005;. Eerikäinen *et al*. 2007).

It can be said that species replacementis widespread in the areas where coniferous forests grow and are actively used. When V. M.Glazyrin and N. I.Vysotsky (Study of forest forming ... KazAGRIReport, 1981) compared the plans of planted forest of Chernevinsky forestry of East Kazakstan Region for the period from 1885 to 1973, it was noted that birch or aspen forestsreplaced fir standsinmany quarters. Materials of forest management fieldworksperformed in 2011 on the territory of the aforementioned forestry and their analysis (Kalachev, 2011) indicate that 58.9% (144.12 ha) of forested lands are occupied by secondary soft-woodedforest stands. In general, in Rudny Altai primary fir standscover 373.34 ha, or 39.3% of the forested lands, and secondary soft-woodedforest stands (birch and aspen) - 392.75 thou. ha, or 41.3% (Kalachev, 2013).

Natural regeneration is the most common and preferred method for birch reproduction in many European countries (Hynynen *et al.* 2010). The birch as a pioneer species actively naturally regenerates if seeds sources are available. The birch is often in this context, especially on poor, depleted soils (Frivold and Borchgrevink, 1981; Karlsson, 2002; Jogiste et al, 2003; Liepins, 2007; Renou et al, 2007; Uri et al, 2007). Stem shoots can be used as a regeneration method in a short-term intensive rotation. In the textbooks, the seeding is often mentioned as a viable option for birch regeneration, but still is not widely practiced. For instance, 11% ofhomogeneous birch stands were formed by seeding in Finland during 1999-2008 (Anonymous, *2008*). The birch regenerates more frequently after clear felling. The size and shape of the clear spot and seed supply requirements tradeoffis important for natural regeneration. Treeseeds can be used in large areas. Natural regeneration of birch is successful in many habitat conditions, when process break is man made or natural.

In Britain (Cameron, 1996) it is recommended to use gradual systems to provide some additional protection, which favorably affects natural regeneration of birch. The recommended number of taller trees (seed trees) with well-developed crown is about 20 to 40 trees per hectare. Karlssonand Albrektson (*2001*) from Japan also believe that gradual thinning can be performed to regenerate birch forests. High density leads to a gradual decrease in birch seedlings survival (Nilsson et al., *2002*). Preparation of the areas promotes natural regeneration (e.g. Sarvas, *1948*; Kinnaird, *1974*; Karlsson, *1996*). Light soils and salinity is a recommended practice in natural regeneration of silver birch (Karlsson and Albrektson, 2001).

The birch is characterized by heavy bearing ability, but there are large variations in the quantity and quality of seeds (Hynynen et. al., 2010). In Northern Europe, abundant seed repeat every 2 - 3 years (Sarvas, 1948; Koski and Tallqvist, 1978). In Central Europe, the birch sets seeds annually (Cameron, 1996). Birch seeds have small brightwings with a good germinating ability (Sarvas, 1948; Jonsell, 2000; Wagner et al, 2004.). Their germination is regulated by the interaction of photoperiod and temperature (Vaartaja, 1952; Black and Wareing, 1954, 1955; Vanhatalo et al, 1996). Wide range, auto crossing, selection, long-distance pollentransfer by wind, abundant seeding and a good seed dispersal allow to maintaingenes flow from one population to another, also a wide genetic variability within populations and constant variability of birch trees (Hamrick et al, 1992;. Eriksson et al., 2003).

The birch is also able to regenerate by vegetative method, by sprouting dormant basal buds, when the apical dominant shoot isweakened or removed due to, for instance, felling or other damage (Kudryavtsev, 1955, Demidovskaya, 1961; Pyatnitsky, 1963 Danchenko, 1982, Denisov, Mayorov, 1987; Kauppi et al, 1987;Perala and Alm, 1990; Kalachev, 2000, 2001). The number of basal buds and ability to produce coppice shoots varies from tree to tree, which is influenced by the age of mother tree, habitat conditions, size and age of the stump, and fellingtime (Ferm and Kauppi, 1990).

Birch vegetative regeneration features were studied in areas subject to 2-10-year-old final felling. Natural regeneration of birch trees after felling was evaluated by the number of stumps regenerated by shoots. Table 4 shows the results of a studiedshoot formation ability of birch on 5-year-old felling.

Analyzing the data given in Table 4, one can conclude that the success of shoot formation process depends on the age of the felled tree. When felling birch forests of seed origin, a 100% regeneration ability is maintained up toVII age class. Shootformationabilityofbirchdecreaseswithageincrease.

Indicators	1,3 m height diameters, cm							Total
	20	24	28	32	36	40	44 and more	
Number of felled trees per 1 ha, %	8.0	15.8	18.9	20.0	21.2	9.3	6.4	100.0
Portion of the stumps formed the shoots, % of total number	100	40.0	36.3	19.0	11.0	0	0	27.0
Age class	VI	VII	VII	VII	VII	VII	VIII	

Table 4: Shoot formation ability of birch depending on age.

When felling trees with a diameter of 24 cm, which correspond to VII ageclass, only 40% of the stumps will be regenerated by the shoots. In the future, the dynamics is getting worse: the proportion of trees capable to form shoots at diameters of 28, 32 and 36 cm is 36.3, 19.0 and 11.0% respectively. After felling trees with a diameter of 40 cm and more there are no shootsrecorded. The birch in VIII age class completely loses shoot formation ability. Thus, within one (VII) age class (61-70 years) first generation seed origin birch completely loses shoot formation ability.

In studying the process of birch origin and further growth of shootsonfelling areas of different remoteness periods, an interesting fact was discovered. The shoots formed on the stump have a different location. One part of the coppice shoot is forming on the side of the stump from dormant buds - we call it stool shoots. The other one begins its growth on root spurs - root shoots. Both stool and root shots have a kind of bending, which is maintained in an adult tree in the basis, in our opinion, caused by two reasons: the first one is that after fresh shoot originates from a bud growing on a vertical surface of the stump or on the side of the root spur, it changes growth direction to vertical. The second one is that fresh shoot originated from a bud on the root spurhas to grow around the sheaf ofshootsoriginated higher along the stump.

Stool and root shootsare formed on the stump simultaneously. After statistical processing of field data, it wasfound that the average number of stool shoots originated on two-year old felling area is 5.7±0.42 pcs and the root shoot is2.5 ± 0.11 pcs. The maximum number of root shoots is 17 pcs, and the minimum is 2 pcs. Maximum number of root shoots is 4 pcs, and the minimum is 1 pc. Table 5 shows the dynamics of birch shoot growth on 2-, 5- and 10-year-old felling area.

In analyzing the course of the stool and root shoots growth it was found that their height is the same in the first few years, i.e. average height of two-year oldstool and root sprouts is 0.6 ± 0.01 m. Later on, it is observed that the growth of root shoots, whichat the age of five has a height of 2.1 ± 0.04 m, becomes more intensive. The height of the stool shoots at this age is 1.9 ± 0.05 m, which is less by 10% than the root one. It can also be noted that the number of stool and root shoots, which have not reached the age of five, remains unchanged, i.e. average number of stool shoots is 4.8 ± 0.43 pcs and root shoots is 2.2 ± 0.6 pc. The maximum number of five-year stool shoots is 16 pcs, and the minimum is 1 piece, at the same time the maximum number of root shoots is 4 pcs, and the minimum is 1 pc.

Remoteness of felling, years	Stool shoots						Root shoots					
	Number, pcs.			Height, m			Number, pcs.			Height, m		
	M±m	max	min	M±m	max	min	M±m	max	min	M±m	max	min
2	5.7±0.4	17	2	0.6 ±0.01	1.0	0.3	2.5±0.1	4	1	0.6 ±0.02	1.0	0.3
5	4.8±0.4	16	1	1.9 ±0.05	3.0	1.0	2.2±0.1	4	1	2.1 ±0.04	3.0	1.0
10	0	0	0	0	0	0	2.0±0.1	4	1	6.1±0.1	7.0	5.5

Table 5: Birch shoots growth on felling areas of different remoteness periods.

Thus, there are no significant differences between the stool and root shoots, which have not reached the age of five. The only difference is the exceedanceof the average height of the root shootsby 10% over that of the stool ones. Additional analysis of stump wood state on felling areas was carried out. Wood density on 2- and 5-year-old felling areas is equal. The wood retains its inherent structure and density.

However, by 10years after felling a different picture is observed. The stool shoots regardless of the tree origin is completely absent. Average height and the number of root shoots is 6.1±0.1 m and 2.0±0.1 pcsrespectively. The maximum number is 4 pcs, and the minimum is 1 pc. We can confidently assert that the root shoots during the first ten years after felling maintain a positive growth dynamics.

Assessment of stump wood state in 10 years after felling showed that the wood has rotted and turned to the rot. There is only a bark (elm) remained on some stumps, according to which it is possible to assess the diameter and the origin of the tree. There are also 4 or even 5-meter dry birch trees on the area, which laidnear the stumps with barksection in basis of the tree. They felled in winter under the snow or its own weight. By the age 10 the stumpwoodhas rotted completely, causing the death of stool shoots. It is observed that the stool shoots felt on cutting 5-year old felling area. However, this fact was not highlighted as fallen trees were regarded as the result of self-thinning.

6. Conclusion

In conclusion, it should be noted that current appearance of Rudny Altai forests is formed under the influence of two factors: forest fires and diverse human activities. Clear felling embedded in the forest industry from the middle of last century, along with forest fires, led to a significant change in the structure and species composition of dark coniferous taiga. Secondarysoft-wooded forests of birch and aspen with an admixture of fir, which area is 383.66 hectares (40.4% of forested land), grow in the area of indigenous coniferous forests. The composition of birch forests depends on ontogeny stage of temporary birch forest.

The middle-aged stands predominate in the birch forests. The capability is characterized by the average growth class - III, and the average density- 0.52. Most next generation birch forestsare provided with fir undergrowth and their accelerated transformation in indigenous coniferous forests is only possible through the timely felling.

Secondary birch forests of the first generation areconventionally uneven-aged and presented by II-VIII and aboveage class trees. As a rule, it is the high-density stands of seed origin.

Seed or vegetative origin of the birch forests playsan important role in natural regeneration. Seedbirches seed retain shoot formation ability for much longer, whereas vegetative birchessingle cases of shoots absenceare observed in VI age class, and in VII class no fifth stump is able to form shoots. By VIII class almost a half of birch trees after felling will not naturally regenerate, and at the age of 91 and more all the birchesdo not regenerate, that is, forest area may change (transfer into the category of shrubs or wastelands) after overmature birch stands dissimilation and in the absence of younger specimens. The ability of vegetative treesto form the shoots in VI and VII age class, in our opinion, depends on total biological age (number of generations). All seed trees in this age regenerate by vegetative method.

The optimal age of seed birch stands designated for final felling is 61-70 years, while vegetative stands should be felledupon reaching 60. The results ofshootsorigin and further growth study indicate that the untimely birch felling, regardless of origin, can lead to complete loss of shoot formation ability. This is especially important for vegetative birch forests.

As for the role of the so-called root shoot in birch stands formation, it may be noted that, according to many researchers, the birch regenerates by vegetative method by means of the shoots formed from dormant buds. Studies show thatthe root shoots only form coppice birch forest. However, it is unknown yet from what buds (dormant or accessory) it is formed because this issue requires further study.

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References

1. Anonymous (2008) Finnish Statistical Yearbook of Forestry. Finnish Forest Research Institute, Helsinki, Finland.
2. Bhat KM, Kärkkäinen M (1980) Distinguishing between Betula pendula Roth. And Betula Pubescens Ehrh. on the basis of wood anatomy. Silva Fenn14: 294-304.
3. Biryukov VN (1982) Groups of Kazakhstan forest types. Alma-Ata: Kaynar Publ. 44 pp.
4. Black M, Wareing PF (1954) Photoperiodic control of germination in seed of birch (Betulapubescens Ehrh.). Nature174, 705-706.
5. Cameron AD (1996) Managing birch woodlands for the production of quality timber. Forestry 69, 357-371.
6. Chernyshov MA (1963) Species replacement on clear felling in the forests of the Middle Urals /Lesnoyekhozyaystvo [The Forestry], 10, 25-27.
7. Danchenko AM (1982) The Birch. Alma-Ata: Kaynar Publ., 85 pp.
8. Demidovskaya LF (1961) Kolochniye lesa Severnogo Kazakhstana, ikh tipy I osobennosti vozobnovleniya: Aftoreferat diss. Kand [Forest outliers of North Kazakstan, their types and regeneration features: Abstract of Doct. Diss.]. Alma-Ata, 21 pp.
9. Denisov AK, Mayorov LI (1987) Influence of felling time and stump height on coppice regeneration. // LesnoyeKhozyaystvo [The Forestry]. 8, 16-17.

10. Eerikäinen K, Miina J, Valkonen S (2007) Models for the regeneration establishment and the development of established seedlings in uneven-aged, Norway spruce dominated forest stands of southern Finland. For. Ecol. Manage. 242, 444-461.
11. Ferm A, Kauppi A (1990) Coppicing as a means for increasing hardwood biomass production. Biomass. 22, 107-121.
12. Fischer A, Lindner M, Abs C and Lasch P (2002) Vegetation dynamics in central European forest ecosystems (near-natural as well as managed) after storm events. Folia Geobot 37: 17-32.
13. Fries J (1964) Yield of BetulaverrucosaEhrh. in Middle Sweden and southern North Sweden. Stud. For. Suec. 14, 1-303.
14. Eriksson G, Black Samuelsson S, Jensen M, Myking T, Rusanen M, et al. (2003) Genetic variability in two tree species, Acer platanoides L. and Betula pendula Roth, with contrasting life-history traits. Scand. J. For. Res. 18: 320-331.
15. Frivold LH, Borchgrevink I (1981) Biomass yield of silver birch (BetulaverrucosaEhrh) in 6 years old trial plantation at As, Norway. Meld. Norg. Landbruks. 60: 1-17.
16. Glazyrin VM (1981) Study of forest forming process in dark coniferous forests of Rudny Altai: Research paper report / Glazyrin V. M. Alma-Ata: KazAGRI, 124 pp.
17. Götmark F, Fridman J, Kempe G, Norden B (2005) Broadleaved tree species in conifer-dominated forestry: regeneration and limitation of saplings in southern Sweden. For. Ecol. Manage. 214: 142-157.
18. Gustavsen HG, Mielikäinen K (1984) Site index curves for natural birch stands in Finland. Folia For. 597: 1-23. [in Finnish with English summary].
19. Hagman M (1971) On self-and cross-incompatibility shown by BetulaverrucosaEhrh. andBetulapubescensEhrh . Commun. Inst. For. Fenn. 73: 1-125.
20. Hamrick JL, Godt MJW, Sherman-Broyles SL. 1992 Factors influencing levels of genetic diversity in woody plant species. New For. 6: 95-124.
21. Helms A, Jørgensen CA (1925) Birkene paa Maglemose. Botanisk Tidskrift. 39: 57-133. [in Danish].
22. Hultén E, Fries M (1986) Atlas of North European Vascular Plants north of the Tropic of Cancer. I Introduction, Taxonomic Index to the Maps 1–996, Maps 1–996.Königstein, Germany: Koeltz Scientific Books.
23. Hynynen J, Niemistö P, Viherä-Aarnio A, Brunner A, Hein S, et al. (2010) Silviculture of birch (Betula pendula Roth and Betula pubescens Ehrh.) in northern Europe. Forestry. 83: 103-119
24. Jogiste K, Vares A, Sendros M (2003) Restoration of former agricultural fields in Estonia: comparative growth of planted and naturally regenerated birch. Forestry. 76: 209-219.
25. Jonsell B, editor. Flora Nordica. 2000 Volume 1. Lycopodiaceae to Polygonaceae. Stockholm, Sweden: The Bergius Foundation, the Royal Swedish Academy of Sciences, 1-344.

26. Johnsson H (1974) Genetic characteristics of BetulaverrucosaEhrh. And BetulapubescensEhrh. Annales Forestales. AnalizaŠ umarstvo. 6: 91-133 + 28 Figs.
27. Kalachev AA (1998) Silvicultural role of the birch in formation of dark coniferous forests of Rudny Altai/GeograficheskiyeosnovyustoychivogorazvitiyaRespubliki Kazakhstan: Sb. mat. konf. in-ta geografii [Geographical bases of sustainable development of the Republic of Kazakhstan: Coll. of conf. proc. of Geography Inst.]. Almaty: Kainar Publ. 195-199.
28. Kalachev AA (2000) Indigenous fir forests regeneration process on Rudny Altai felling areas and the the role of the birch in this process / Kalachev A. A. // Issledovaniyairezultati [Studies and results]. 2: 192-197.
29. Kalachev AA (2001) Rol' berezyvlesoobrazovatelnomprotsessevpikhtarnikakhRudnogoAltaya: avtoref. Diss….kand. s.-kh. nauk: 06.03.03 [The role of the birch in Rudny Altai fir forests formation: Abstract of Diss....M Agr: 06.03.03] / Kalachev AndreyAleksandrovich. Almaty, 30 pp.
30. Kalachev AA, Arkhangelskaya TA (2011) Dynamics of Rudny Altaifir forests/VestnikAGAU [BulletinofAGAU] 5: 29-33.
31. Kalachev AA, Izergina MO (2013) Post-fire dynamics of dark coniferous forests of Kazakhstan Altai/Issledovaniyairezultati [Studiesandresults] 2, 98-104.
32. Karlsson A (1996) Initial seedling emergence of hairy birch and silver birch on abandoned fields following different site preparation regimes. New For 11: 93-123.
33. Karlsson A, Albrektson A (2001) Height development of Betulaand Salix species following precommercial thinning through breaking the tops of secondary stems: 3-year results. Forestry 74: 41-51.
34. Kauppi A, Rinne P, Ferm A (1987) Initiation, structure and sprouting of dormant basal buds in Betulapubescens. Flora. 179: 55-83.
35. Kinnaird JW (1974) Effect of site conditions on the regeneration of birch (Betula pendula Roth. and B. pubescensEhrh.) J Ecol 62: 467-472.
36. Koivisto P (1959) Growth and yield tables. Commun. Inst. For. Fenn. 51: 1-49.
37. Kolesnikov BP (1960) Some patterns of age and regeneration dynamics of cedar forests of TransuralsPriobye / Kolesnikov BP, Smolonogov Ye. P. // Problemykedra [Cedar issues]. Novosibirsk: SDofAoSofUSSR, 21-31.
38. KominG. Ye (1967) The impact of fire on the age structure and growth of the north-taiga water-logged pine forests of Transurals / Komin G. Ye. // TipyidinamikalesovSibiriiZauralya[Types and dynamics of the forests of Siberia and Zauralye]. Sverdlovsk, 68-75.
39. Koski V, Tallqvist R (1978) Results of long-time measurements of the quantity of flowering and seed crop of forest trees. Folia For. 364: 1-60.
40. Kudryavtsev KA (1955) Some features of birch regeneration // Lesnoyekhozyaystvo [The Forestry] 5: 12-13.
41. Kujala V (1946) Some recent data on birches. Commun. Inst. For.Fenn. 34: 1-36.

42. Kurbatsky NP (1964) Forest fire issues / Vozniknoveniyelesnykhpozharov [Forest fires development]. M.: Nauka Publ., 5-60.
43. Liepins K (2007) First-year height growth of silver birch in farmland depending on container stock morphological traits. Balt For. 13: 54-60.
44. Lugansky NA, Zalesov SV, Shchavrovsky VA (1996) Lesovedeniye [The Silviculture]. Ekaterinburg, 373 pp.
45. Lundgren LN, Pan H, Theander O, Eriksson H, Johansson U, et al. (1995) Development of a new chemical method for distinguishing between Betula pendula and Betulapubescensin Sweden. Can. J. For. Res. 25: 1097-1102.
46. Melekhov IS (1948) Vliyaniyepozharovna les [Fire impact on the forests]. M.,L.:Goslestekhizdat Publ.126 pp.
47. Morozov GF (1913) Speciesreplacement /Lesnoyzhurnal [Forestjournal]. 7: 5-18.
48. Morozov GF (1930) Ucheniye o lese [Theory of forest management]. M.,L. 5: 412.
49. Mushegyan AM (1962) DerevyaikustarnikiKazakhstana[TreesandbushesofKazakhstan]. Alma-Ata: KazselkhozgizPubl. 1: 364.
50. Mushegyan AM (1966) DerevyaikustarnikiKazakhstana[TreesandbushesofKazakhstan]. Alma-Ata: KaynarPubl 2: 344.
51. Niemistö P (1995) Influence of initial spacing and row-to-row distance on the growth and yield of silver birch (Betula pendula). Scand. J. For. Res. 10: 245-255.
52. Nilsson U, Gemmel P, Johansson U, Karlsson M, Welander T (2002) Natural regeneration of Norway spruce, Scots pine and birch under Norway spruce shelter woods of varying densities on a mesic-dry site in southern Sweden. For. Ecol. Manage. 16: 133-145.
53. Oikarinen M (1983) Growth and yield models for silver birch (Betula pendula) plantations in southern Finland. Commun. Inst. For. Fenn. 113: 1-75.
54. OST 56-44-80 (1980) Forest management and silvicultural signs. Types, sizes and general technical requirements.
55. OST 56-69-83 (1983) Forest management sample plots. Pledge method.
56. Perala DA, Alm AA (1990) Regeneration silviculture of birch - A review. For. Ecol. Manage. 32: 9-77.
57. Popov LV (1983) South taiga forests of Central Siberia. Irkutsk: Publ. of Irkutsk Univ. 330 pp.
58. Pyatnitsky SS (1963) Vegetative forest. Moscow: Publ. of agricultural books, journals and posters 135 pp.
59. Raulo J (1977) Development of dominant trees in Betula pendula Roth. And BetulapubescensEhrh. plantations. Commun. Inst. For. Fenn. 90: 1-15.
60. Renou F, Scallan U, Keane M, Farrell EP (2007) Early performance of native birch (Betulaspp.) planted on cutaway peatlands: influence of species, stock types and seedlings size. Eur. J. For. Res. 126: 545-554.
61. Romanovsky AM (1996) Succession changes in anthropogenically disturbed forest ecosystems / Tezisydokladov [Scientific conference abstracts]. Moscow. 1: 106-108.

62. Sannikov SN (1973) Forest fires as evolutionary and ecological factorofpinepopulationregenerationinTransurals /Goreniyeipozharyvlesu [Forestfires]. Krasnoyarsk: Inst. offorestandwoodof SDofAoSofUSSR, 236-277.
63. Sarvas RA (1948) Research on the regeneration of birch in South Finland. Commun. Inst. For. Fenn. 35: 1-91.
64. Seversky EV (1971) Guidelines for determining the types of dark coniferous forests site and zoning in Rudny Altai. Alma-Ata, 75 pp.
65. Sukachev VN (1928) Plant association / Vvedeniye v fitosotsiologiyu [Introduction to phytosociology]. Sbr.,M., 232 pp.
66. Tkachenko M. Ye (1955) General Forestry. M., L.: Goslesbumizdat Publ. 599 pp.
67. Uri V, Lohmus K, Ostonen I, Tullus H, Lastik R, et al. (2007) Biomass production, foliar and root characteristics and nutrient accumulation in young silver birch (Betula pendula Roth.) stand growing on abandoned agricultural land. Eur. J. For. Res. 126: 495-506.
68. Vaartaja O (1952) Forest humus quality and light conditions as factors influencing damping-off. Phytopathology. 42: 501-506.
69. Vanhatalo V, Leinonen K, Rita H, Nygren M (1996) Effect of prechilling on the dormancy of Betula pendula seeds. Can. J. For. Res. 26: 1203-1208.
70. Wagner S, Walder K, Ribbens E, Zeibig A (2004) Directionality in fruit dispersal models for anemochorous forest trees. Ecol. Model. 179: 487-498.